THE GSETT-3 EXPERIMENT AND THE PROTOTYPE INTERNATIONAL DATA CENTER

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ABSTRACT

On February 20, 2000 the International Data Center (IDC) operated by the Provisional Technical Secretariat of the CTBT Organization in Vienna assumed responsibility for the generation of IDC products and the distribution of IDC products and International Monitoring System (IMS) data. This marked the end of the Group of Scientific Experts third Technical Test (GSETT-3) that started continuous operation on January 1, 1995. During the five years of GSETT-3 the Prototype IDC (PIDC) at the Center for Monitoring Research (CMR) acquired data from over 200 seismic, hydroacoustic, infrasonic and radionuclide facilities worldwide. Automatic processing and subsequent analysis of these data led to Reviewed Event Bulletins (REB) that were issued for every single day, except May 8-14, 1995, between January 1995 and February 2000 and that contained 99,212 events. Over 50 nations participated in GSETT-3 through the operation of sensor facilities, provision of data and bulletins, and staffing the PIDC.

During GSETT-3 participation steadily increased and new functionality was added to the PIDC every few months. Many new features were provided by a variety of DTRA contractors and several foreign agencies. A visiting scientist program brought scientists from many countries to participate in the development, operation and evaluation of the PIDC. Initially only seismic data were processed and analyzed, but hydroacoustic and radionuclide data were incorporated in 1996 and infrasonic data in 1998. Both automatic and reviewed bulletins include signal detections from all three acoustic technologies, and over 15% of REB events have associated hydroacoustic T-phases; infrasonic associations are much rarer. The history of participation in GSETT-3, and improvements in, and additions of new features to, processing and analysis are summarized.

GSETT-3 bulletins have been used by the USGS National Earthquake Information Center and the International Seismological Centre (ISC), and have markedly improved the products of these two agencies. The standardized and centralized processing and analysis of data at the PIDC from a global network of high-quality stations have reduced event detection thresholds in many parts of the world, increased the number of magnitude estimates, and added to the percentage of events for which secondary phases, particularly core and depth phases, are reported. The ISC has noted a significant decline in the number of events that they find for the first time, particularly in the oceans and the Southern Hemisphere.

The software developed for, and tested at, the PIDC is being transferred to the IDC in Vienna in a series of software releases of which the third is being delivered in September 2000. These software deliveries will be completed early in 2002. Until then the PIDC will continue to acquire and process data, and produce reviewed bulletins at a frequency sufficient to test and evaluate improvements to software and operational parameters such as improved detection and association “recipes”, event characterization measurements, and corrections to improve location and magnitude determinations.

Key Words:

Seismic, hydroacoustic, infrasonic, international participation, bulletins, global seismicity

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Introduction

The Group of Scientific Experts (GSE) of the United Nations Conference on Disarmament met in Geneva for one or two sessions each year from 1976 to 1996. Its primary function was to discuss, develop and test the procedures that would be needed to verify compliance with a CTBT. During two decades, over 50 countries participated in the work of the GSE, which operated by consensus – all reports and the procedures, formats and tests that they developed had to have unanimous agreement. The work of the GSE provides the basis of the verification system that is described in the Treaty and is now being implemented in the International Monitoring System, which includes the International Data Centre in Vienna. The procedures developed by the GSE were thoroughly tested in a series of experiments called Technical Tests. The initial test, GSETT-1 – GSE Technical Test number 1 - was conducted in 1984 and involved the exchange of phase readings over the telex-based World Meteorological Organization (WMO) Global Telecommunications System (GTS). A much more ambitious test (GSETT-2), involving the exchange of both phase readings and the corresponding waveform segments (in the first of the "GSE" formats) by both WMO/GTS and email, and the processing of these data by four International Data Centres (IDCs) located in Canberra, Moscow, Stockholm and Arlington (Center for Monitoring Research - CMR) was carried out over a six-week period in 1992. This experiment established the superiority of email over the telex system, demonstrated that many countries could implement the quite complex procedures, and acted as a starting point for the development of the basis of the future IDC. It proved a very complex task to reconcile the output of the four IDCs, and one major conclusion was that one IDC would be preferable.

Discussions on the next generation of the system began almost immediately after the conclusion of GSETT-2. Rapid political changes removed long-standing objections to the exchange of real-time continuous waveform data. Detailed procedures for the IDC were developed, and a number of small experiments conducted in data exchange. The CMR was designated as the single prototype IDC (PIDC) and significant extra funding permitted its rapid development, with initial data receipt from northern Europe (Norway, Germany and a few others) during 1993 and 1994 testing data acquisition and the processing of data from regional arrays. This signified the start of GSETT-3, and the PIDC produced and distributed sporadic bulletins on a trial basis. The full-scale phase of GSETT-3 began on January 1, 1995, with continuous waveform data from over 50 stations being received, processed and analyzed on a daily basis. Analysis and bulletin production and distribution was carried out on a 7-day per week basis, with bulletins being distributed within 48 hours after the end of the data day. The capability of the PIDC improved rapidly over the next few years. The number of stations providing data to the PIDC increased quite rapidly over the first six months, and much more slowly thereafter.

This paper describes the history of GSETT-3, largely from the perspective of the PIDC. The changes in station data processing and analysis are given in a series of tables. The PIDC was very much an international effort, with participation in its development, operation and evaluation by visitors to CMR from over 30 countries.

Contributing Data Network

The number of seismic stations whose data were used by the PIDC peaked in mid-1996. The drop thereafter was primarily due to discontinuing use of non-IMS stations in Europe, North America and Australia. The number of auxiliary stations used fluctuated as cost of telephone calls to non-AutoDRM sites became a concern. In late 1998 auxiliary station access was restricted to those for which data retrieval was by AutoDRM. The first hydroacoustic and infrasonic sites came online in late 1995, and radionuclide data were first received in 1996.

Since 1997 there has been some change in the mix of stations of a particular technology reporting to the PIDC, but little change in the overall station count, except for a modest increase in the number of infrasound stations.

Detection Processing

This includes both detection and phase identification. For arrays, phase identification is established from the observed slowness, while for three component stations, neural nets use a variety of signal features. Tuning of both processes has been carried out as more data accumulated.

1993	–May 3	GSETT-3 begins, primary data detection processing at NDCs, retrieved by PIDC
	–May 5	auxiliary data detection processing at PIDC
1994	–Mar 4	tune detection processing for auxiliary stations in Germany
	–Apr 16	neural net phase identification (NNPI)
	–Jun 26	primary data detection processing at PIDC
1995	–Jun 2, Aug 10, Oct 25, Nov 24	tune detection processing
1996	–Jan 27	new detection processing software (DFX)
	–Jan 27, Feb 27, Apr 9, May 2, Aug 25, Oct	tune detection processing
	–Aug 19	hydroacoustic detection processing
	–Oct 14	tune P/Pn crossover in phase identification
1997	–Apr 18, May 28	tune detection processing
	–Jun 6	tune NNPI
	–Jul 25	improved error estimates for detection times
1998	–Jan 1	large array detection processing (NORSAR)
	–Feb 24	tune detection processing
	–Apr 3	tune NNPI
	–Apr 8	infrasonic detection processing, probabilistic times for hydroacoustic detections
	–Oct 23	NNPI for hydroacoustic detections
2000	July	Hydroacoustic azimth estimation, depth-phase SNR

Hydroacoustic Processing

Only two IMS hydrophone stations, and one T-phase station, are operating at present. This, combined with the lack of data from explosive underwater sources, has hampered tuning efforts, but considerable success has been achieved with the detection and association of T-phases from earthquakes. T-phases are associated with approximately 20% of all events in the REBs.

1995	–Sep 1	First continuous hydroacoustic data (PSUR)
1996	–Apr 8	Operational hydroacoustic processing
	–Apr 15	Retrieve T-phase data from island auxiliary stations
	–Apr 22	hydroacoustic analysis
	–May 5	hydroacoustic associations in published REB
	–Aug 19	automated hydroacoustic processing
1997	–Apr 30	hydroacoustic fusion with seismic bulletin, time-defining H phase
1998	–Oct 23	Neural net phase identification for hydroacoustic arrivals
	–Apr 8	probabilistic arrival times, 2D travel times

Infrasound Processing

As for hydroacoustic, shortages of data, particularly from arrays with configurations close to that required for the IMS, plus a lack of "ground truth" (signals from confirmed sources at known locations) have led to slow progress. Neverthless, infrasonic signals associated with earthquakes in the REB have been detected, along with a number of rocket (shuttle, etc) launches and a number of events whose occurrence could not be independently confirmed.

1995	–Nov 12	First continuous infrasound data (WRAI)
1998	–Apr 8	infrasound processing
	–Dec 1	infrasound arrivals in automated bulletins and REB
1999	–Dec 1	First IMS infrasound array (ISM, Canada)
2000	July	Laterally and seasonally-varying travel times

Network Processing

The association of signals from seismic, hydroacoustic and infrasound stations is a difficult problem, particularly since the low detection levels used result in frequent overlapping of signals from different events. The criteria for event definition are more liberal than those of other agencies such as the USGS NEIC and the ISC. Laterally varying seismic travel times for regional phases are used in Northern Europe and North America, and the travel times for both hydroacoustic and infrasonic signals are both laterally and seasonally dependent.

1993 –May 3 GSETT3 begins, PIDC uses ESAL for network processing, Travel times are IASPEI
1994 –Jul 27, Oct 29 modify event-definition criteria
- -Oct 4 M8.2 Kurile Islands event: scaling problem with ESAL
1995 –Jan 20 tune network processing
1996 –Jan 21 tune network processing
–Mar 1 new network processing software (GA)
1997 –May 19 fusion of hydroacoustic data and seismic data
–Aug 22 first regional travel times: Fennoscandia
1998 –Jan 5 Slowness-Azimuth Source Corrections (SASCs)
–Apr 8 hydroacoustic 2D travel times
–Dec 1 fusion of infrasonic data
1999 –Jan 19 GSASC - global (all ranges and azimuths) SASCs
–Apr 1 Single-Station Source Corrections (SSSCs), Northern Europe
2000 –Jan 11 SSSCs, North America
2000 July Updated SASCs; corrections for station misorientation

Analysis

The goal of the IDC system is to automate detection, phase identification and association as much as possible, so the work of the analysts consists of confirming, correcting and adding to the automatic results. The starting point for analysis is the last of three successive automatic event lists. At the present time, parameters for detection, phase identification and association are set so that approximately half of all events are rejected by the analysts, and roughly ten percent of the events in the REB are not created by the automatic processing and have to be added during analysis. Feedback from the analysts has proved extremely important in guiding the improvement of the prior automatic processes.

1993 –May 15 analysis begins, 2 days/week, 2 analysts. Primary data is only event segments, northern Europe.
1994 –Feb 5 Primary network and REB now global
–May 14 First continuous primary data (continuous analyst scan)
–Sep 3 Analysis increased to 3 days/week
–Oct 29 Analysis increased to 4 days/week
1995 –Jan 1 Continuous analysis (7 days/week), 9 - 12 analysts, 7 days. REB released within 48 hours.
–May 10 database failure (5 days), no REB May 8 - May 14
1996 –Jan 7 Severe winter storms on Jan 7 and 12 shut down DC area. REB is produced on schedule
–May 1 Two-team independent analysis experiment demonstrates variation in REB is primarily near threshold of system.
–May 5 hydroacoustic analysis
–Jun 15 7-day analysis in 5-day work week, REB in 48 - 120 hours
–Jun 25 end of daily scanning
–Jul 8 Two-pass auxiliary data analysis experiment demonstrates only minor improvements with much more auxiliary data
1997 –Mar 28 database failure (4 days), REB produced every day.
1998 -Dec 1 infrasonic analysis
2000 –Feb 20 Full-scale operation of IDC, end of 7-day REB at PIDC, 3 analysts

Magnitude Estimation

The PIDC has broken new ground in magnitude estimation, with the routine operational use of path-dependent Ms, maximum likelihood magnitudes, and most recently with “generalized” mb – mb extended to short distances. Most of this development has been carried out by Maxwell Technologies

1993 - May 3 GSETT-3 begins with only simple ML
1994 - Mar 19 reliable amplitude measurements for mb
- May 20 tune mb
1995 - Apr 9, Oct 31 tune ML
- May 18 first MS
1996 - Apr 17 Tune Ms
- Dec 18 Recall processing adds magnitudes for analyst-added arrivals
1997 - Jan 12 Maximum Likelihood Ms
1998 - Apr 12 Maximum likelihood and upper bound mb and Ms in REB
2000 -.July “Generalized mb, including station corrections; Ms station corrections

Event Characterization

The IDC will not identify events, but does compute event characterization parameter and uses them to “screen” events. This work has been largely carried out by Mission Research Corporation and the Australian NDC

1994 –Mar 19 reliable amplitude measurements for mb
1995 –May 18 Ms first available
1996 –Jul 10 first two event characterization computations available:
origin-based frequency-dependent amplitudes, short-period/long-period ratio
–Aug 1 additional computations: - spectral variance, cepstral quefrencies and peak amplitudes, complexity
1997 –Mar 14 Event Characterization Bulletin
1998 –Apr 8 further computations - third moment of frequency,time-frequency parameters first-motion
2000 July Screening based on hydraocoustic signal properties and regional P/S amplitudes

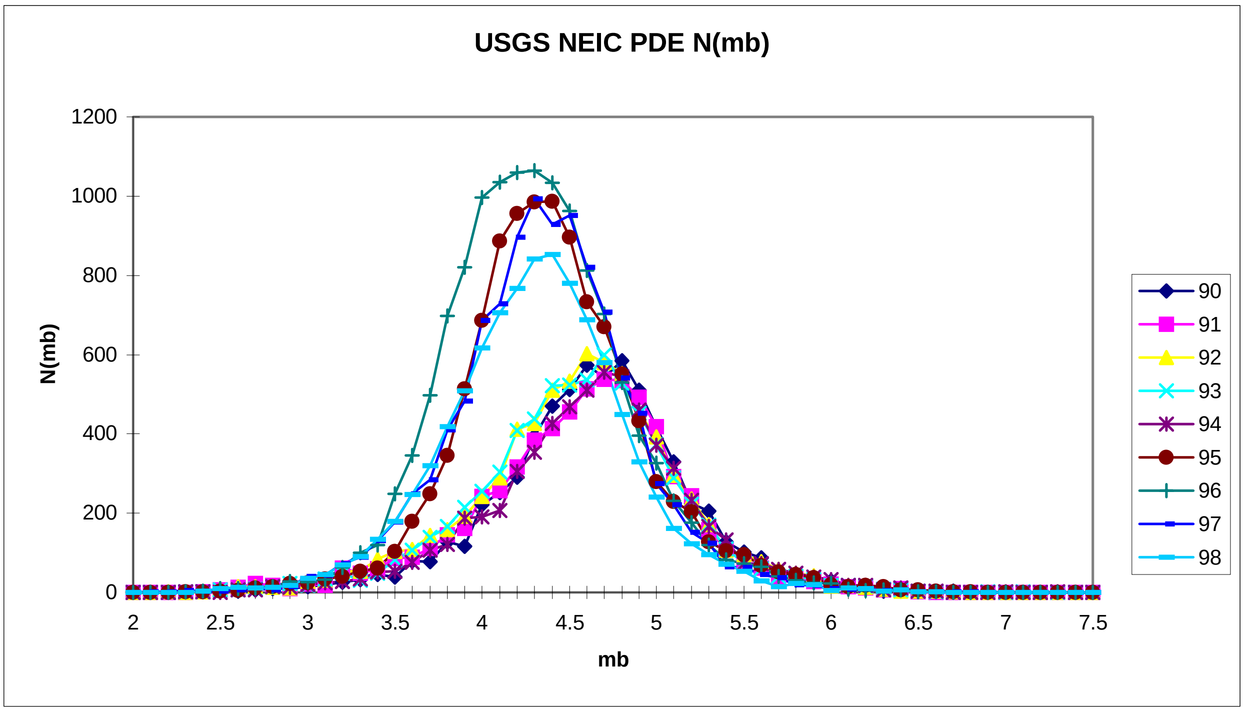
Product and Data Distribution

Rapid dissemination of results and the contributing raw data is a key element of the system. Both results and data have been made available through a web page, subscriptions (automatic delivery of products/data as they are generated/received) and AutoDRM (mail-based request system).

1993 –May 15 REB 2 days/week. REB distributed in GSETT2 format.
1994 –Jun 16 First continuous primary data. forwarding available.
–Dec 1 AutoDRM
1995 –Jan 1 Continuous REB
–Jan 13 PIDC web page, version 2 (web available to all)
–May 22 constrained subscriptions
1996 –Jan 4 near-realtime AutoDRM.
–Dec 2 automated subscription requests, "immediate" subscriptions
1997 –Mar 14 event characterization bulletin
–Mar 26 arrival and detection subscriptions, Jul 17 waveform subscriptions
–Oct 24 flat-file product subscriptions
1998 –Apr 8 GSE2.1 (IMS1.0) message formats
–Jul 31 event screening
1999 –Jan 6 Threshold monitoring maps on web
2000 –Apr 14 Secure web server available for products after 2000 Feb 20.
-Apr 21 Auto DRM restricted for products after 2000 Feb 20.
July Validation/signing of messages; forwarded auxiliary data requests

Impact of PIDC Products on Other Bulletins

The PIDC REBs have been quite extensively used by both the NEIS and the ISC as input to their bulletin products. The phase readings included in the REBs are used as part of the data input for the NEIS and the ISC, and have significantly increased the numbers of events located by both. Because nearly every REB teleseismic P-wave detection is accompanied by amplitude and period readings, the proportion of events with associated m_b magnitudes has increased sharply. The special effort by the PIDC analysts to identify and report depth phases has similarly improved the proportion of events to which depths other than a default value, such as 33km, can be assigned. The ISC has noted that the number of "new" events that they create, mainly in the southern oceans, from unassociated teleseismic observations has decreased significantly as the PIDC does particularly well in this area. The figure below shows magnitude-frequency curves for events with mb magnitudes in the USGS NEIC bulletin, by year. Note the sudden increase in the number of events in 1995, when NEIC started using PIDC phase reports.



The five lower curves (peaking at about mb 4.7) are for the years 1990, 1991, 1992, 1993, and 1994. The other four curves are for 1996 to 1998. The increased reporting of events with mb is a combination of events that could only be formed with phase data from the PIDC, and magnitudes provided only by the PIDC for teleseismic events.

International Participation

Foreign visitors and contributors have played a key role in the development, testing and operation of the PIDC. Norway and Australia have contributed software for Threshold Monitoring, large array processing, and event characterization. Areas in which foreign contributions have been made include–location calibration

–event characterization
–radionuclide processing development
–infrasound processing development
–hydroacoustic system evaluation
–magnitude studies
–operations (analysis, "pipeline" operation, QC)

Summary

The development and operation of the Prototype IDC

–helped establish the technical capability to monitor the treaty
–served as the platform for international technical cooperation
–advanced the state of monitoring technology
–demonstrated performance that corroborates theoretical predictions
–had a pronounced, beneficial, collateral effect on global monitoring
–serves as the operational test and evaluation platform for transition to the Treaty IDC
–will provide an on-going testbed for research and development in nuclear test-ban monitoring